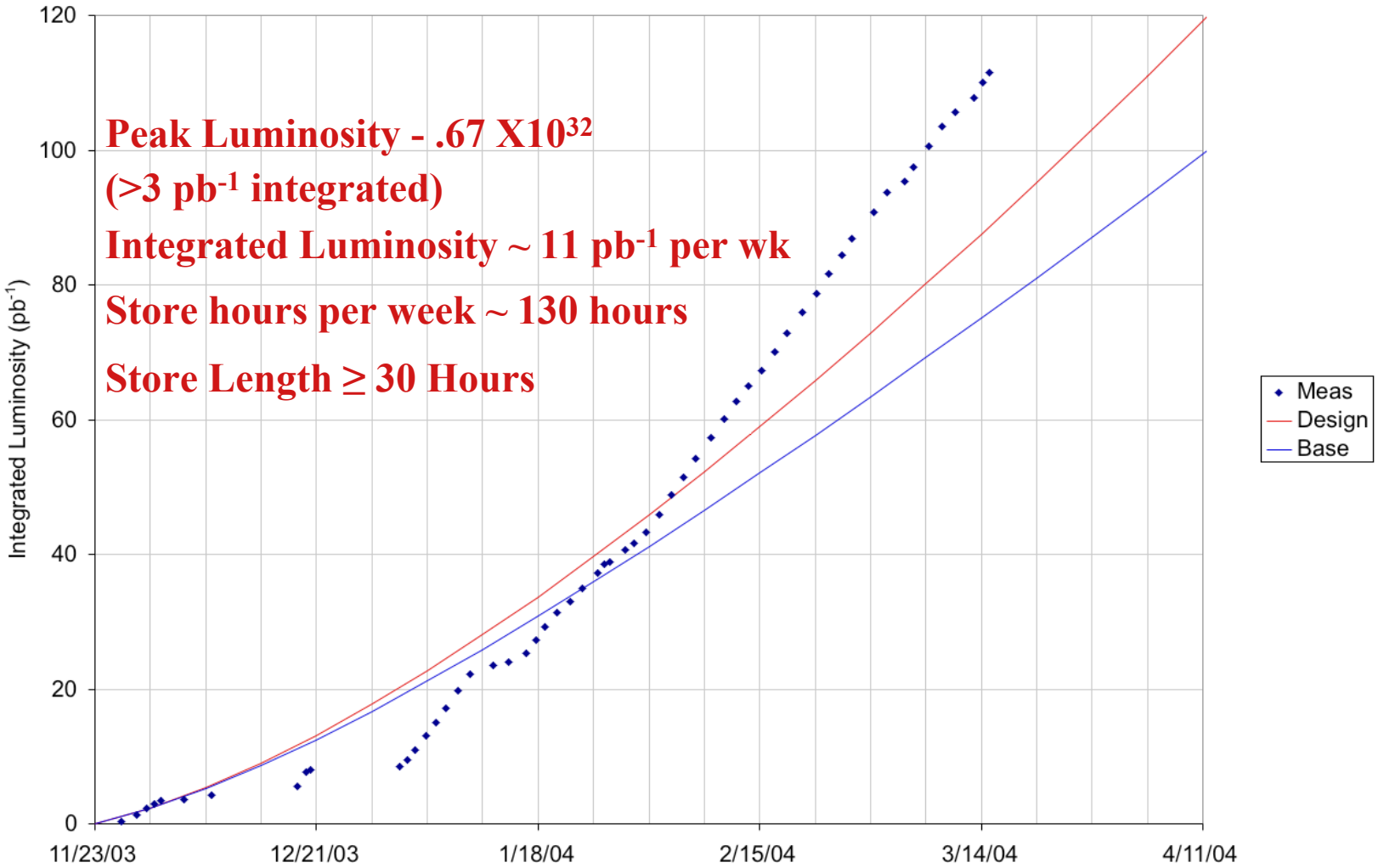
Run II Luminosity Review Summary

R. Dixon

FY04 Integrated Luminosity



Run Plan

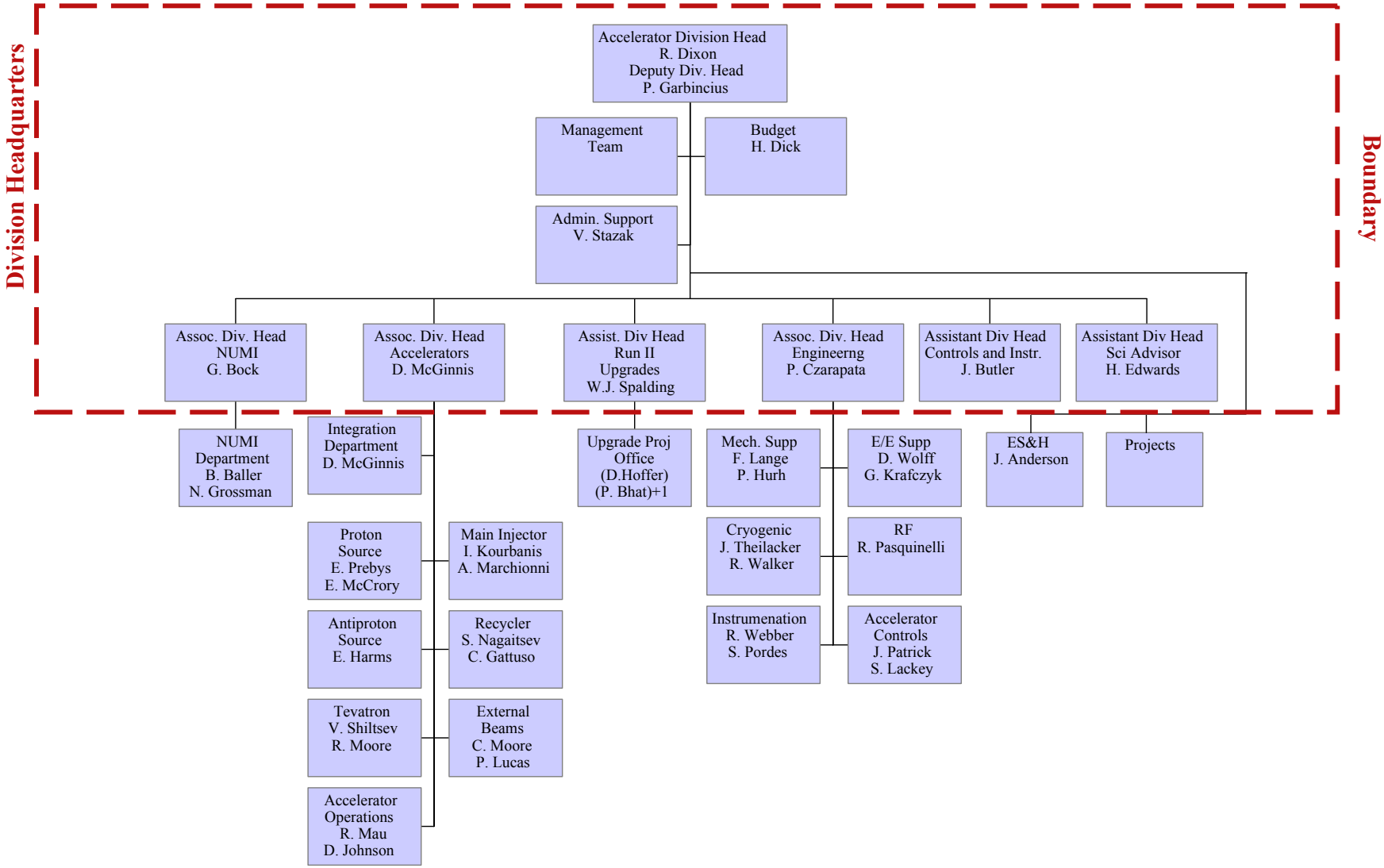
- Discuss Accelerator Division Overview and Organization-- briefly
  - How does Run II fit into this
- The Run II "Upgrade" Plan
- Status of Run II
  - Achievements
  - Challenges

Accelerator Division Overview

- Run II
  - Operations
    - Reliability Improvements
    - Performance Improvements
  - Upgrades
    - Run II Upgrade Projects
    - Run II reliability projects
- Fixed Target
  - Operations
  - Upgrades
    - Proton Plan
- Accelerator R&D
  - Fermilab NiCADD Photoinjector Laboratory (FNPL).
  - Study Groups

"...Run II is a complex campaign of..."

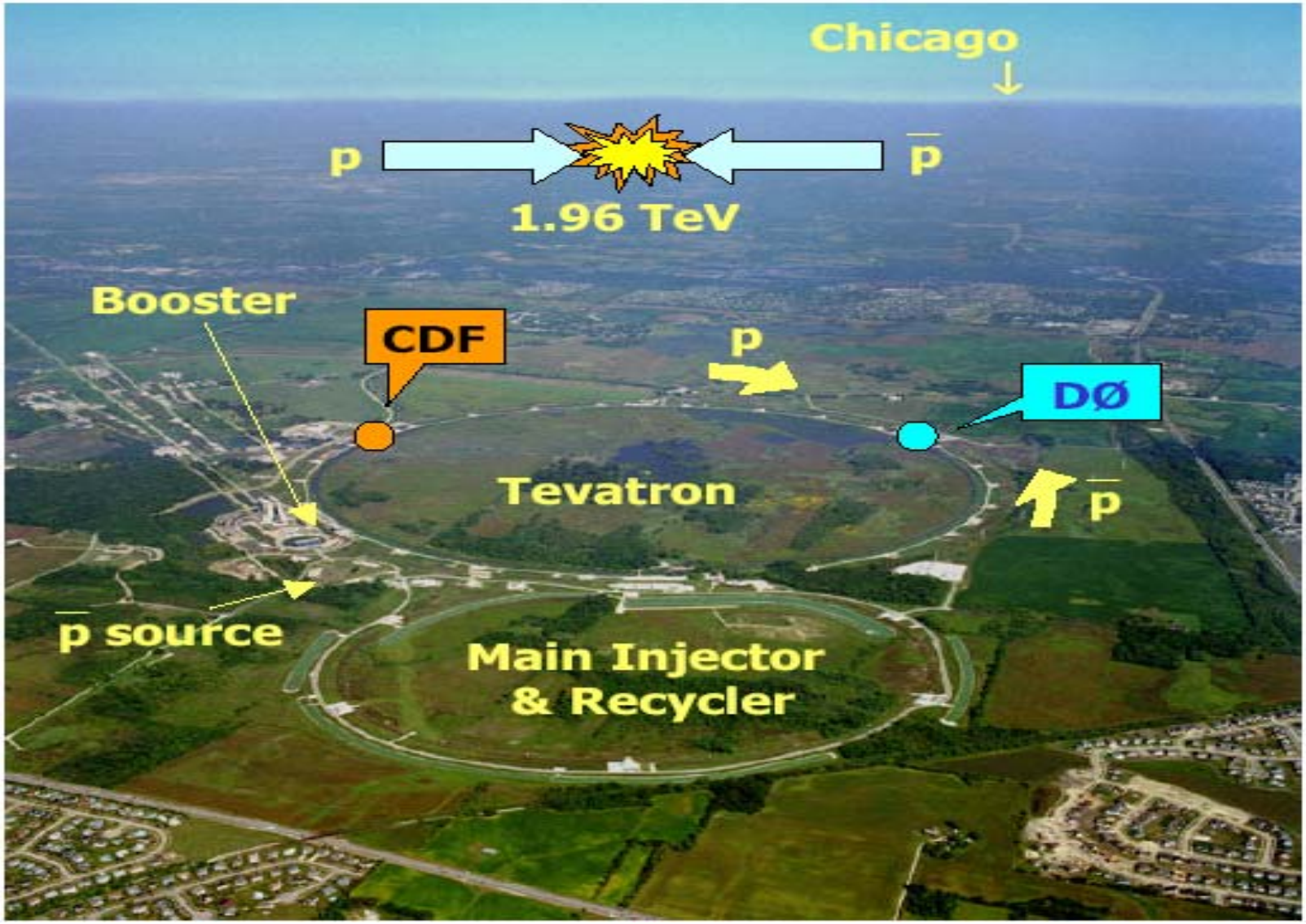
Accelerator Division Organization



Run II Goals for the AD Organization

- Maximize the Performance of the Accelerator Complex to achieve the goals of the Run II physics program
  - Increase reliability
  - Operate efficiently and effectively
  - Make improvements that will increase performance of the accelerator complex
- Need a plan for organization that incorporates operations and improvements
  - Organization to maximize integration
    - Established a dedicated group of people under strong leadership to focus on and to be responsible for Run II operations, studies, and reliability
      - This group developed a systematic approach to the problem of operating and improving the accelerator complex
    - Charged an assistant division head with the responsibility to create the "plan" for improving the luminosity potential of Run II
      - The Run II Luminosity Plan (Version 2.0)
        - » Includes upgrades required to increase the Luminosity
        - » And improvements designed to increase the reliability of the complex
      - Created a project office to support the development and execution of this plan

Accelerator Complex



Run II Luminosity Upgrades

Performance Goals:

- Peak Luminosity Goals:
  - Design → 2.7×10^{32} $cm^{-2}sec^{-1}$ (x 4 - 5 over current)
  - Base → 1.6×10^{32} $cm^{-2}sec^{-1}$ (x 3 over current)

- $\int L.dt$ Goals (By FY09):
  - Design → 8.5 fb^{-1}
  - Base → 4.4 fb^{-1}

Strategy:

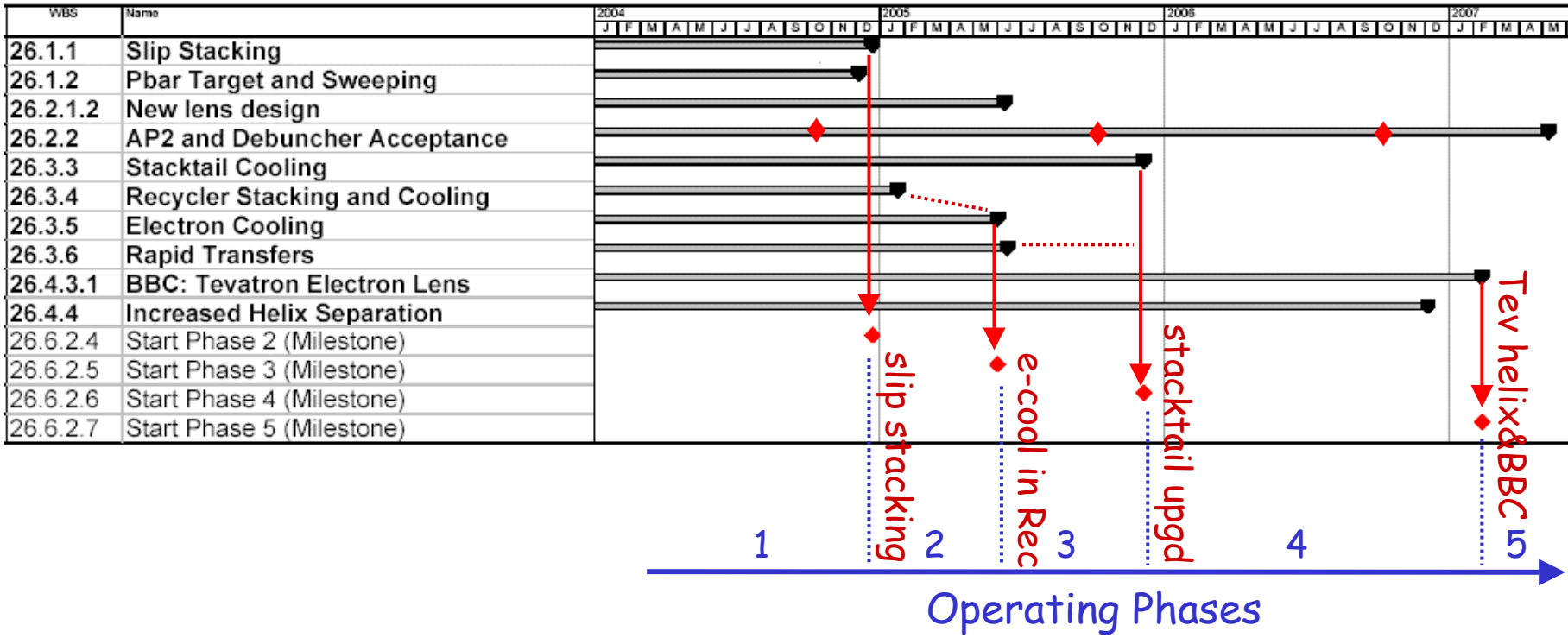
- Increase antiproton production rate & stack size
- Upgrade the Tevatron for higher bunch intensities

Principal Elements of the Plan

- Increase antiproton production by increasing number of protons on the production target
  - ➔ Protons on pbar target (8E12 ppp; x2 more pbars)
- Increase antiproton collection efficiency
  - Upgrade the antiproton collection lens
  - Increase the aperture of the antiproton collection transfer line (AP2) and the Debuncher ring.
  - ➔ Antiproton Acceptance (x2)
- Increase the antiproton stacking and storing capabilities
  - Increase the flux capability of the Accumulator stacktail stochastic cooling system.
  - Use the Recycler as a second antiproton storage ring
    - Transfer stacks of pbars from Accumulator to Recycler, periodically
    - Use both stochastic and electron cooling in the Recycler to maintain large stacks of antiprotons with desired beam properties.
  - ➔ Antiproton Stacking and Cooling (x3)
- Upgrade Tevatron to efficiently handle higher intensity bunches.
  - ➔ Tevatron High Luminosity

Subprojects and Operating Phases

WBS	Name
26.1.1	Slip Stacking
26.1.2	Pbar Target and Sweeping
26.2.1.2	New lens design
26.2.2	AP2 and Debuncher Acceptance
26.3.3	Stacktail Cooling
26.3.4	Recycler Stacking and Cooling
26.3.5	Electron Cooling
26.3.6	Rapid Transfers
26.4.3.1	BBC: Tevatron Electron Lens
26.4.4	Increased Helix Separation
26.6.2.4	Start Phase 2 (Milestone)
26.6.2.5	Start Phase 3 (Milestone)
26.6.2.6	Start Phase 4 (Milestone)
26.6.2.7	Start Phase 5 (Milestone)



- Parallel projects with largely independent resources (although many resources heavily shared with operations)

Cost Summary v2.0

Summary in $FY03

$K (in $FY03)	**v2.0**	**v1.0**
M&S Base estimate	16,461	14,965
M&S Contingency estimate	7,356	7,462
M&S Total	**23,817**	**22,427**
Labor Base estimate	17,980	18,194
Labor Contingency estimate	9,213	9,706
Labor Total	**27,193**	**27,900**
M&S+Labor Total	**51,010**	**50,327**

⬅ $1.4M

⬅ -$0.7M

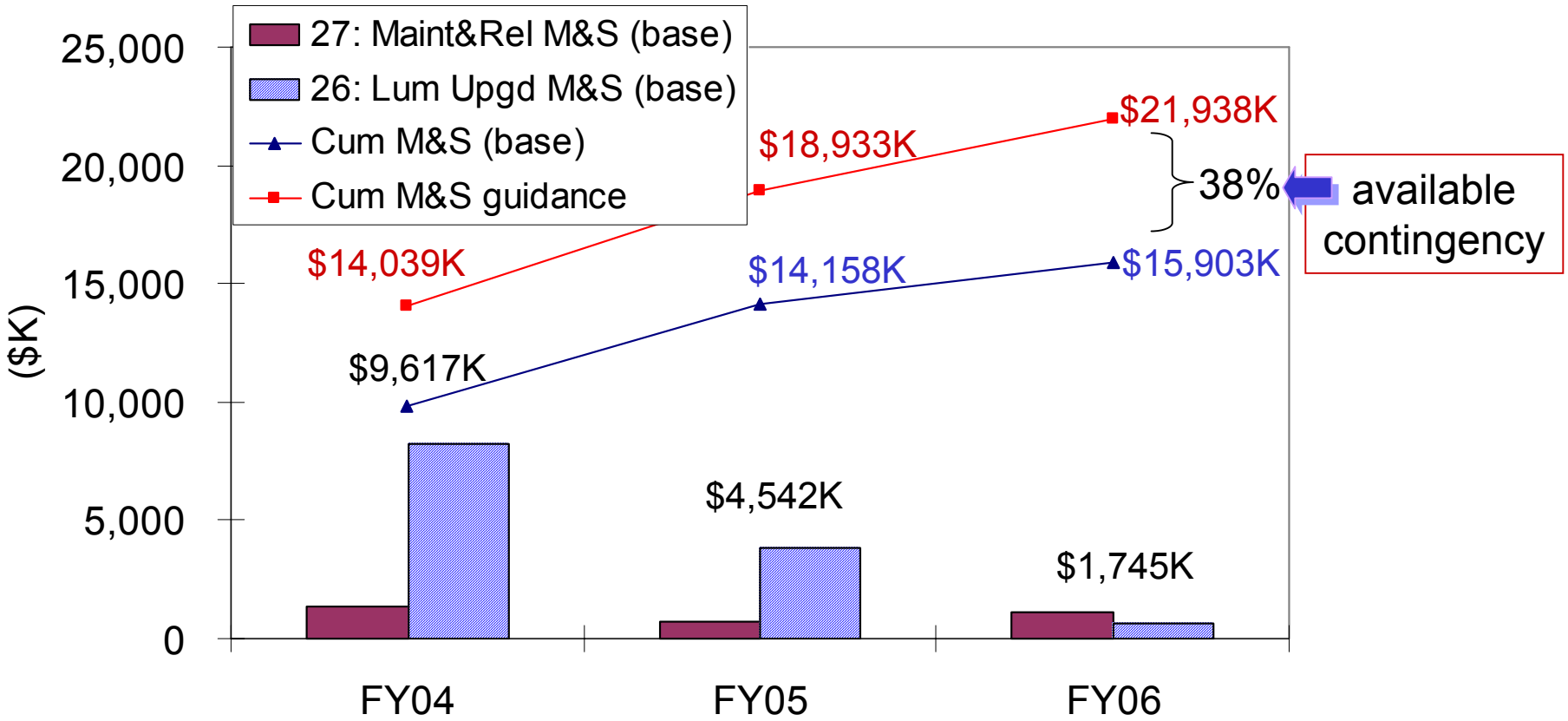
Total contingency roll-up

v2.0: 45% (M&S) and 51%(SWF)

v1.0: 50% (M&S) and 53%(SWF)

M&S Profile v2.0

M&S Profile FY04-06 compared to guidance (actual yr $)

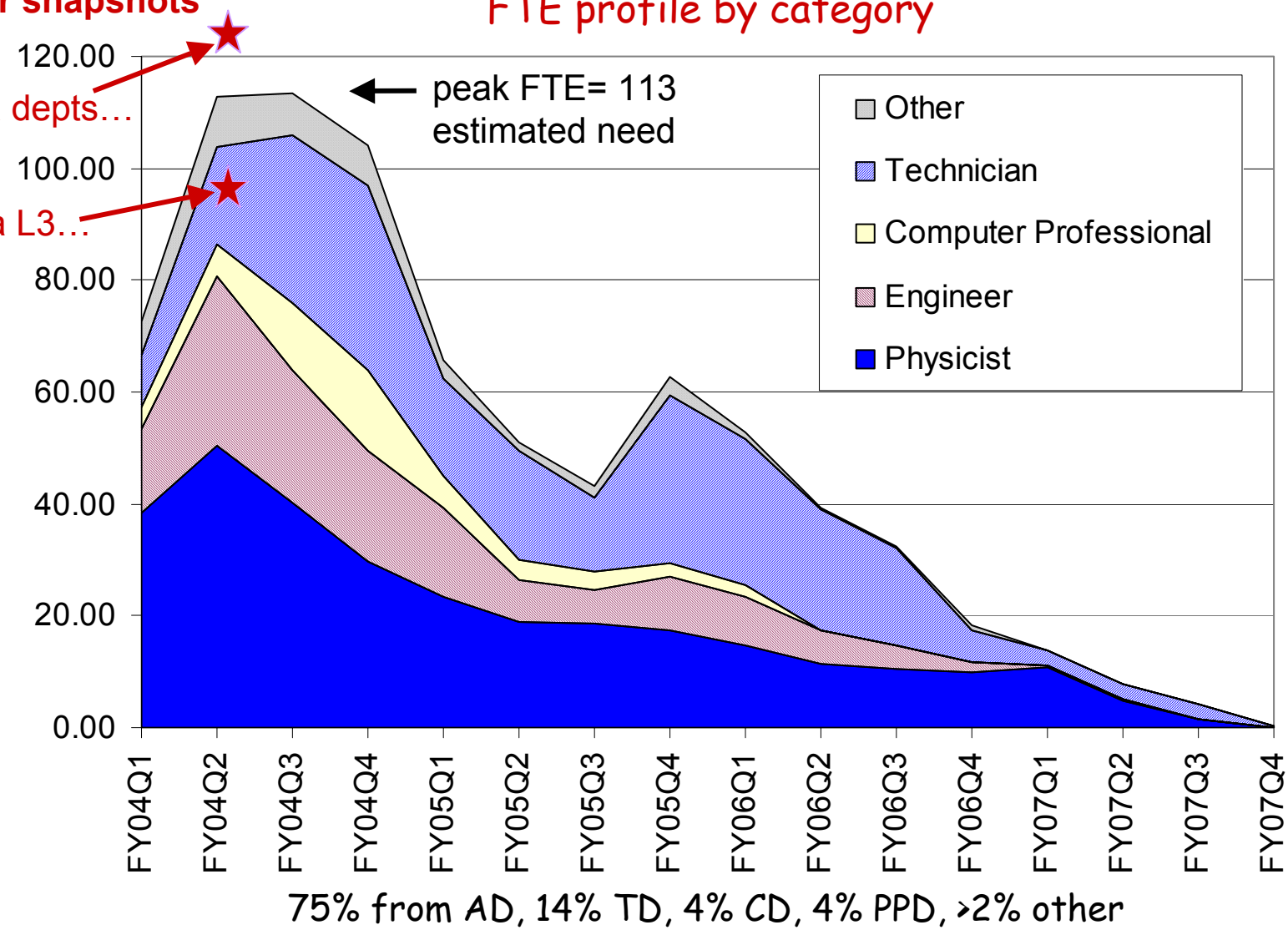


Labor Profile v2.0

Actual labor snapshots
Feb 9-13

snapshot via depts…
FTE= 125

snapshot via L3…
FTE= 96



75% from AD, 14% TD, 4% CD, 4% PPD, >2% other

Luminosity Projection

- Model incorporates
  - Performance parameters from parametric modeling and data
  - Long term operating experience
  - Shutdowns + 1 week to turn on + recovery curve
  - Phase starts + learning slope

- What's new
  - Shutdowns and phase dates from v2.0
  - Pbar "tax" explicit for Recycler & e-cool commissioning (previously ~incorporated in study time)
  - Continue to assume 85 store hours per week average

Design and Base Projections

Subprojects are technically challenging, some entail significant R&D

- Technical and schedule risk

However, subprojects are in parallel

- Both performance parameters and schedules are largely independent (except through operations and shutdowns)

ign Projection

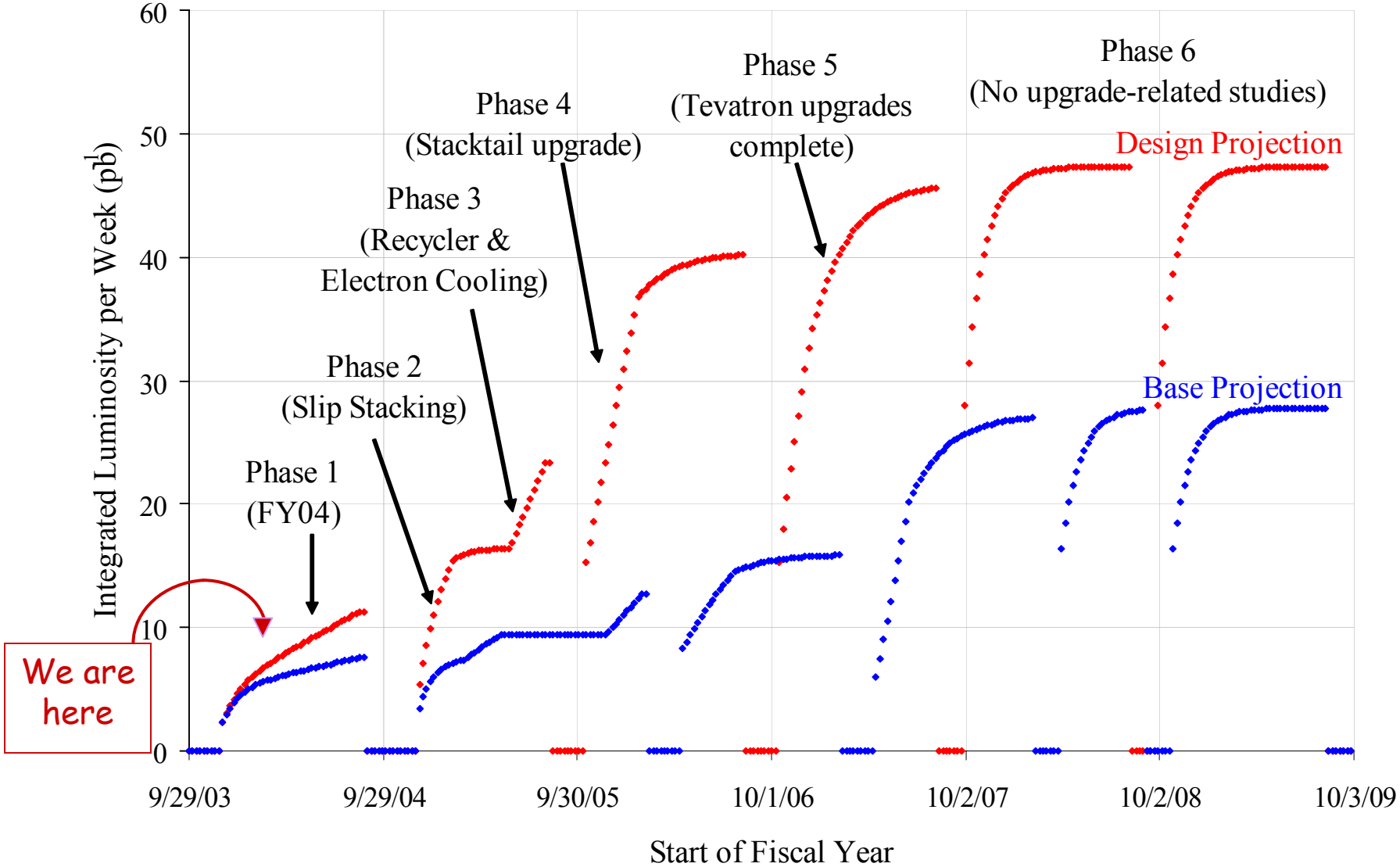
- No schedule contingency, maintains eng. design margin per subproject

Base Projection

- Schedule slip for all subprojects and assumes all subprojects under perform

  (Base projection includes 3 months slip for Phase 2, and 6 months to all other phases ← all phases are delayed)

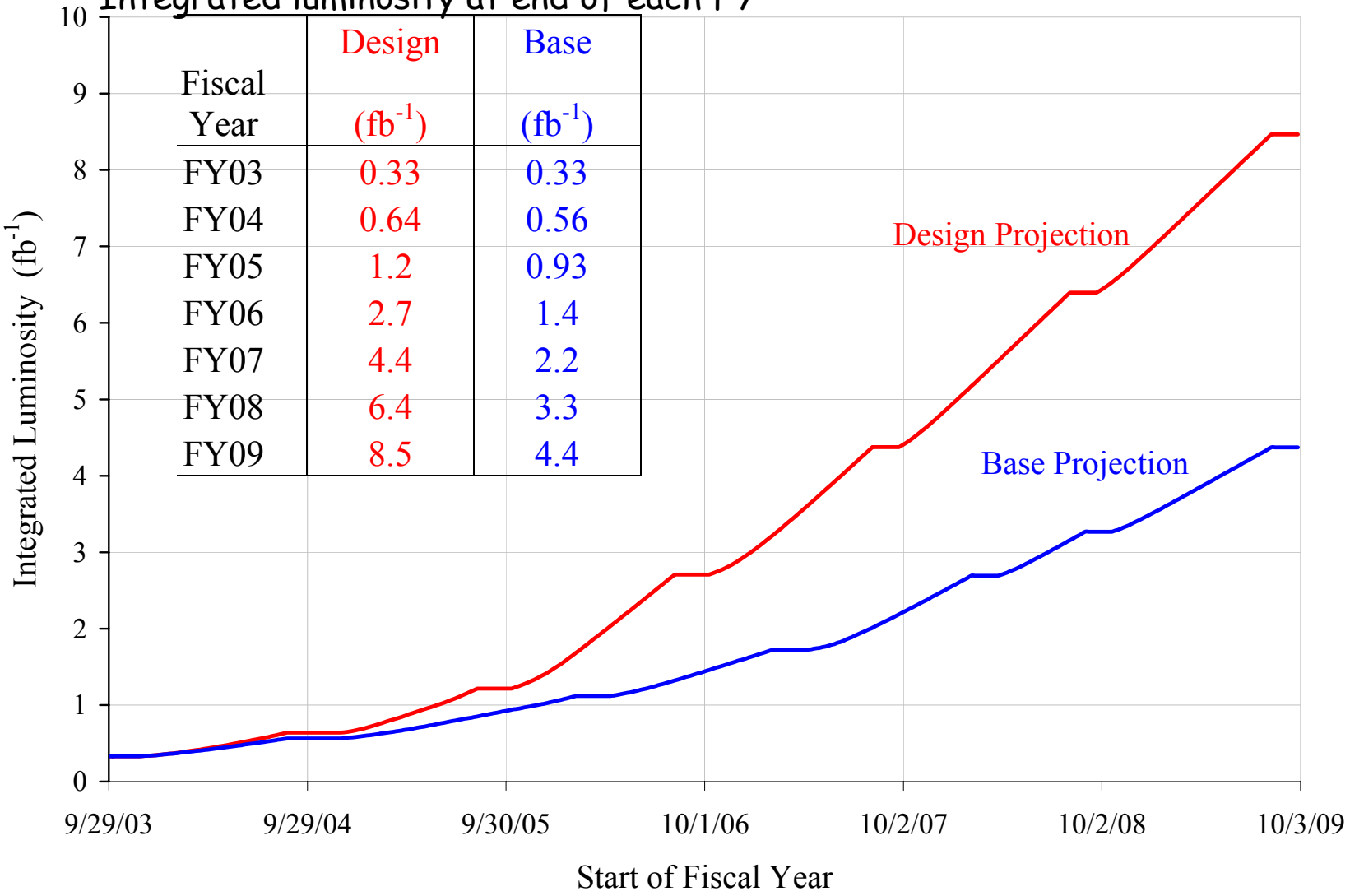
Design and Base Projections



Design and Base Projections

Integrated luminosity at end of each FY

Fiscal Year	Design (fb^{-1})	Base (fb^{-1})
FY03	0.33	0.33
FY04	0.64	0.56
FY05	1.2	0.93
FY06	2.7	1.4
FY07	4.4	2.2
FY08	6.4	3.3
FY09	8.5	4.4



Risk Analysis / Strategy

- Our plan is to deliver the Design Projection
  but develop strategy for fallback scenarios:

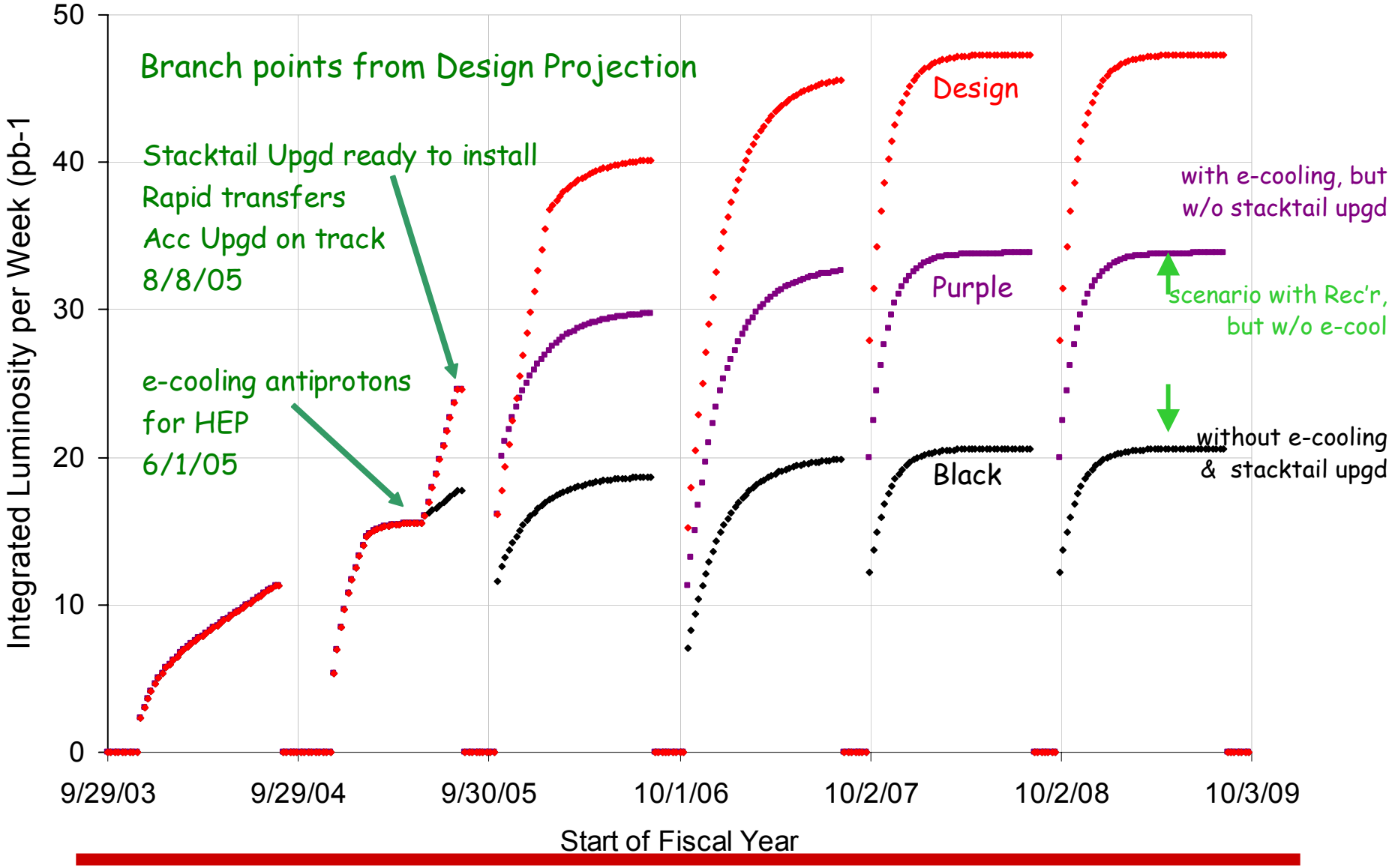
- Base Projection models particular schedule slip and under- performance for all upgrades

- Can also ask: where would we be
  - without Recycler & e-cooling?
  - with e-cooling, but without stacktail upgrade?

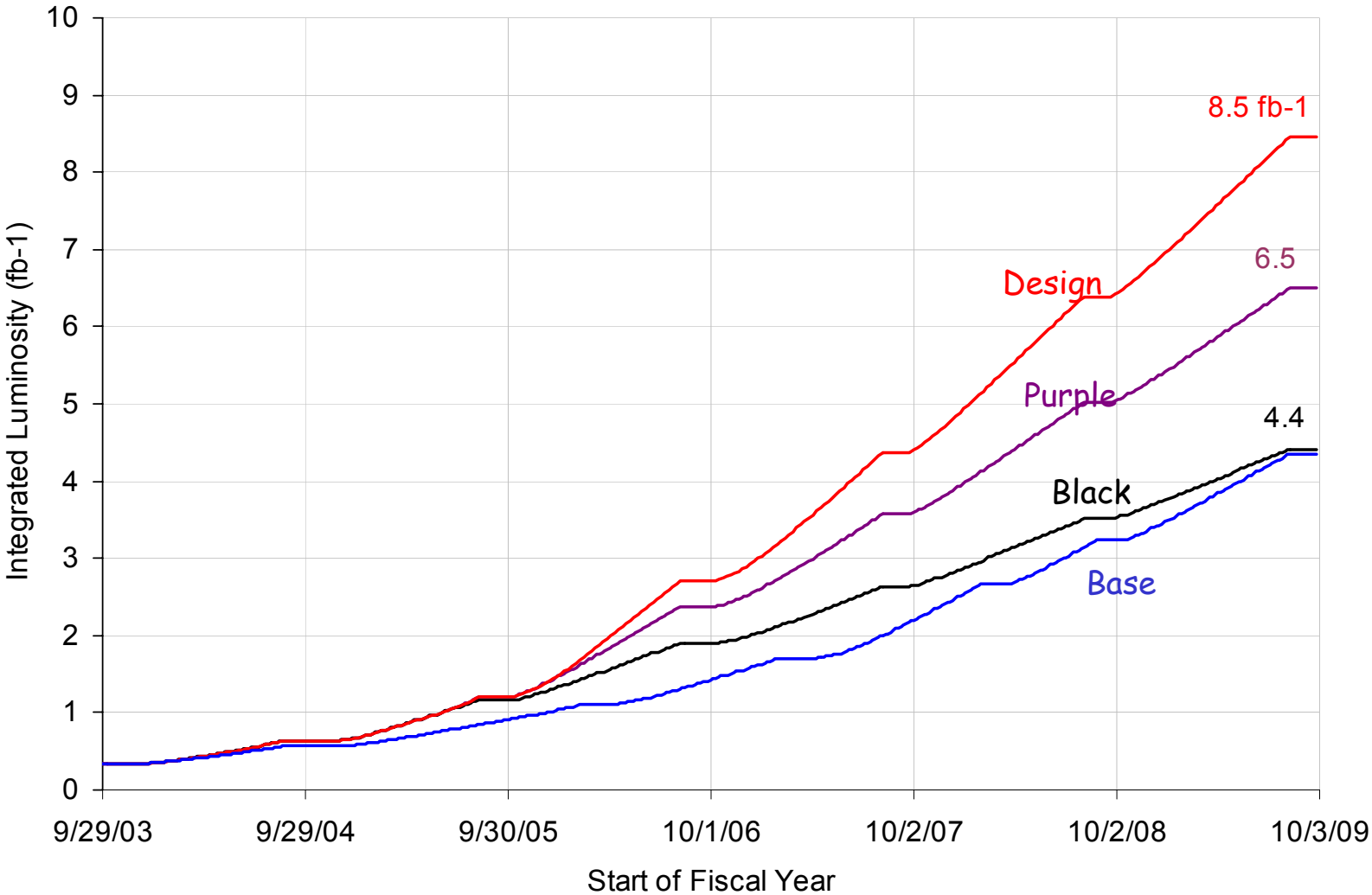
Risk Analysis / Strategy

- **Design Projection**
  - Electron Cooling
  - Stacktail Upgrade
  - Parameters in FY09
    - Debuncher & AP2 at 32π-mm-mrad
    - Slip Stacking at 8×10^{12} ppp
    - Av. Stk Rate = 39×10^{10}/hr
    - Stk in Accum = 20×10^{10}
    - Stk in Rec'r = 570×10^{10}
- **Base Projection**
  - As above with sched & param slip
  - Parameters in FY09
    - Debuncher & AP2 at 25π
    - Slip Stacking at 7×10^{12} ppp
    - Av. Stk Rate = 24×10^{10}/hr
    - Stk in Accum = 24×10^{10}
    - Stk in Rec'r = 360×10^{10}
- **Black Projection**
  - NO Electron Cooling
  - NO Stacktail Upgrade
  - Parameters in FY09
    - Debuncher & AP2 at 21π
    - Slip Stacking at 7×10^{12}
    - Av. Stk Rate = 14×10^{10}/hr
    - Stk in Accum = 205×10^{10}
    - Stk in Rec'r = 0×10^{10}
- **Purple Projection**
  - Electron Cooling
  - NO Stacktail Upgrade
  - Parameters in FY09
    - Debuncher & AP2 at 20π
    - Slip Stacking at 8×10^{12}
    - Av. Stk Rate = 23×10^{10}/hr
    - Stk in Acum = 58×10^{10}
    - Stk in Rec'r = 337×10^{10}

Risk Analysis / Strategy



Risk Analysis / Strategy



Technical Progress Highlights (1)

- Upgrades & operations progressing hand-in-hand
- A lot has been accomplished since July 2003
  - Extensive preparations & huge amounts of resources were dedicated to the 2003 shutdown activities
    - Major Undertakings:
      - Tevatron Alignment & Repairs
      - Recycler Ring bake-out and vacuum work
    - Spectacular success in both cases
  - A dozen technical reviews held
    - Project scopes better defined
    - Technical designs and production decisions made
  - Tevatron had major focus
    - Helix improvements in the Tevatron
    - Tevatron optics, lattice, luminosity modeling
    - Tevatron Instrumentation on aggressive schedule: BPMs, IPM, …
    - Tevatron performance already close to FY04 goals and is expected to improve with the aid of new and improved instrumentation

Technical Progress Highlights (2)

- Slip stacking of protons in the MI
  - Potential to double proton intensity on pbar target by merging two booster batches. Demonstrated to near design intensities, but need to reduce long. emittance ← need full implementation of Beam Loading Compensation (BLC), in progress
- 2.5 MHz Acceleration of pbars in the MI
  - Keeps long. emittance growth to <50% instead of 100 - 140% and eliminates beam loss ; Potential to provide ~20% increase in peak luminosity. Good progress with proton tests; needs BLC
- Booster-MI cogging
  - Achieved resolution of ~ 2 buckets, further improvement underway
- New heat-resilient materials tested for pbar target
- New improved Lithium lens design with diffusion-bonded Ti body
- Small improvements in AP2+DB acceptance, lot of groundwork performed
- Recycler Performance Criteria approved; commissioning plan developed and reviewed. Excellent progress made in Recycler Commissioning.
- First collider shot with pbars from Recycler on Jan. 23, 2004. Recycler is now a "working machine".

- The upgrade project management will put emphasis and focus on the Antiproton stacking & cooling projects in the coming year.

Major Accomplishments of the Fall 2003 Shutdown

- Proton Source
  - Installation of the new dogleg magnets in one of the extraction regions
  - Installation of large aperture magnets in the beginning of the transfer line from Booster to Main Injector
  - Installation of the Booster Collimation System
- Antiproton Source
  - Installation of the motorized Debuncher Quad Stands
  - Installation of the Debuncher BPM System
  - Survey and alignment of the AP2 line
  - Installation of the new equalizers for the Debuncher momentum cooling BAW notch filters
- Main Injector
  - Installation of the NUMI extraction Lambertsons and transfer line
  - Instrumentation relocation for NUMI

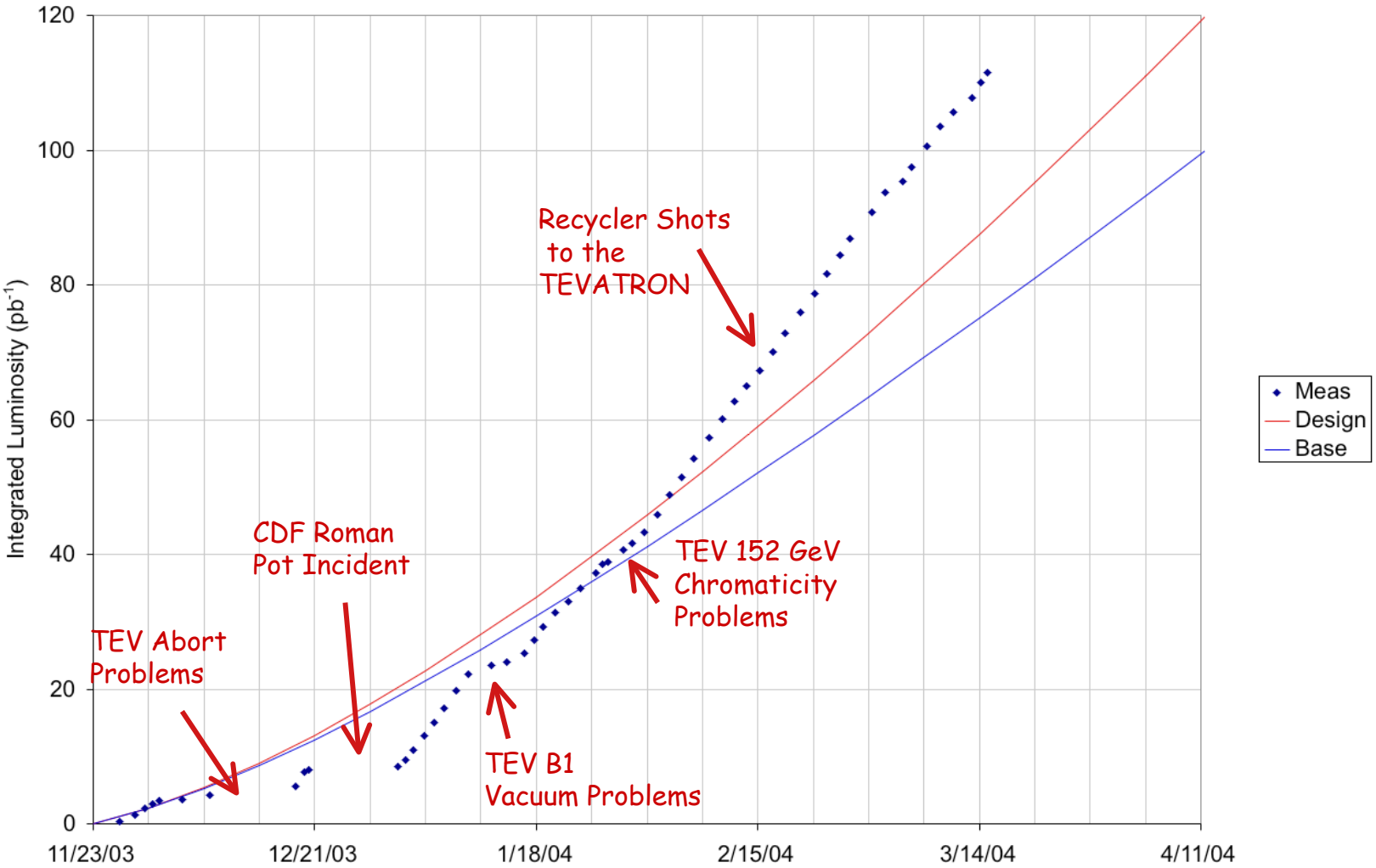
Major Accomplishments of the Fall 2003 Shutdown

- TEVATRON
  - Installation of a ring-wide laser tracker alignment network
  - Complete survey of all TEV magnets
  - Un-roll dipoles with rolls > 1 mrad
    - Rolls over 4 mrad had to be done warm – 100% complete
    - Rolls under 4 mrad can be done cold – 60 - 70% complete
  - Re-alignment of the several devices for aperture increase
  - Alignment of the D0 triplet
  - Smart bolt retrofit
    - Remove sag in magnets that can cause coupling
    - Done in B & D sectors because of the lack of skew correctors in this region
  - Replacement of ~50 aging magnet stand pairs

Major Accomplishments of the Fall 2003 Shutdown

- TEVATRON (continued)
  - Shielding of the F0 Lamberston laminations to reduce the transverse impedance of the TEVATRON
  - Re-wiring of the octupole circuits
    - Differential chromaticity between pbar and proton helices
    - Increase Landau damping
  - New sextupole circuit for decoupling injection helical orbits
- Recycler
  - Complete ring-wide bake
  - Replaced 170 ft of contaminated vacuum pipe
  - Upgraded vacuum instrumentation
  - Finished the ion pump upgrade
  - Additional magnetic shielding added

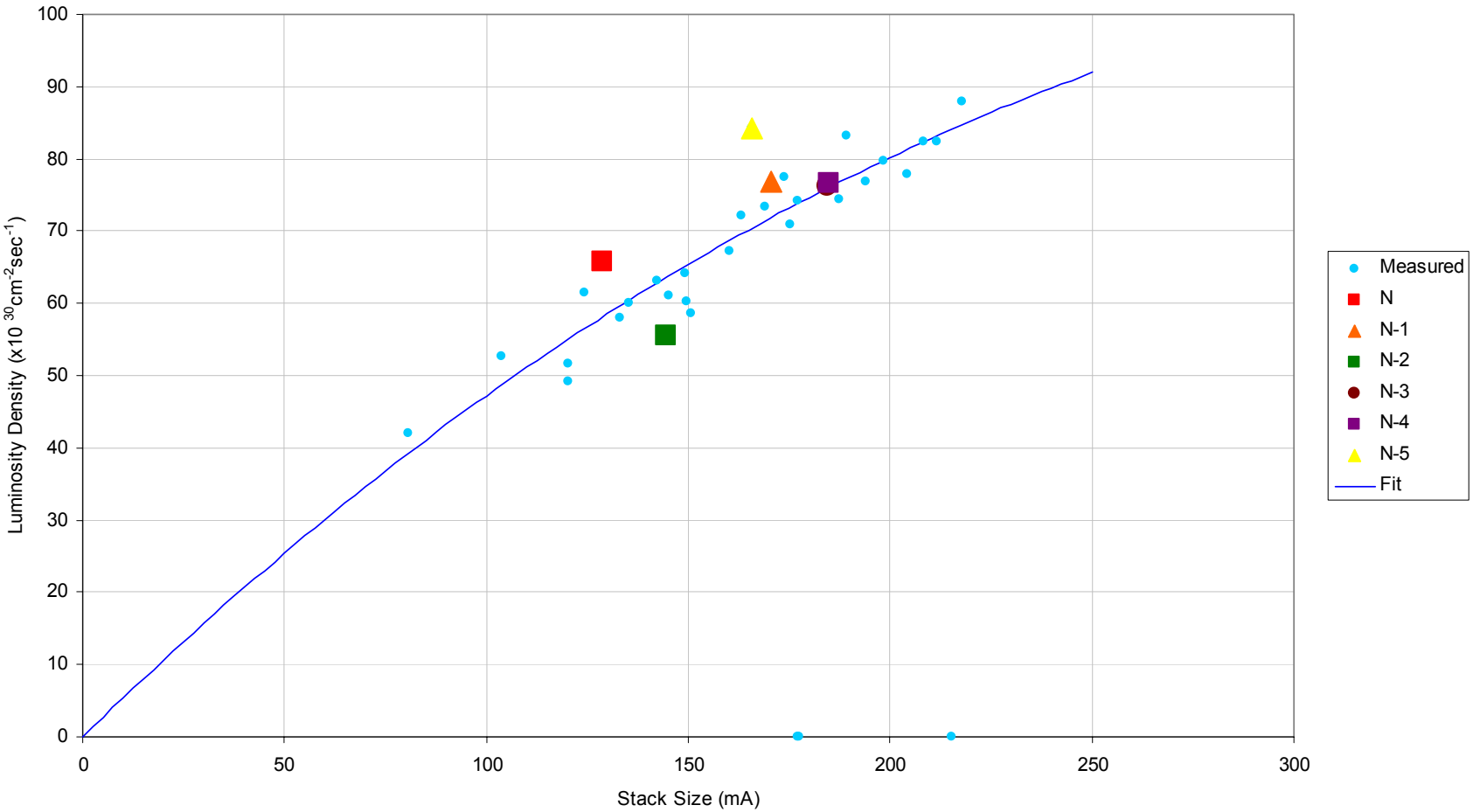
FY04 Integrated Luminosity



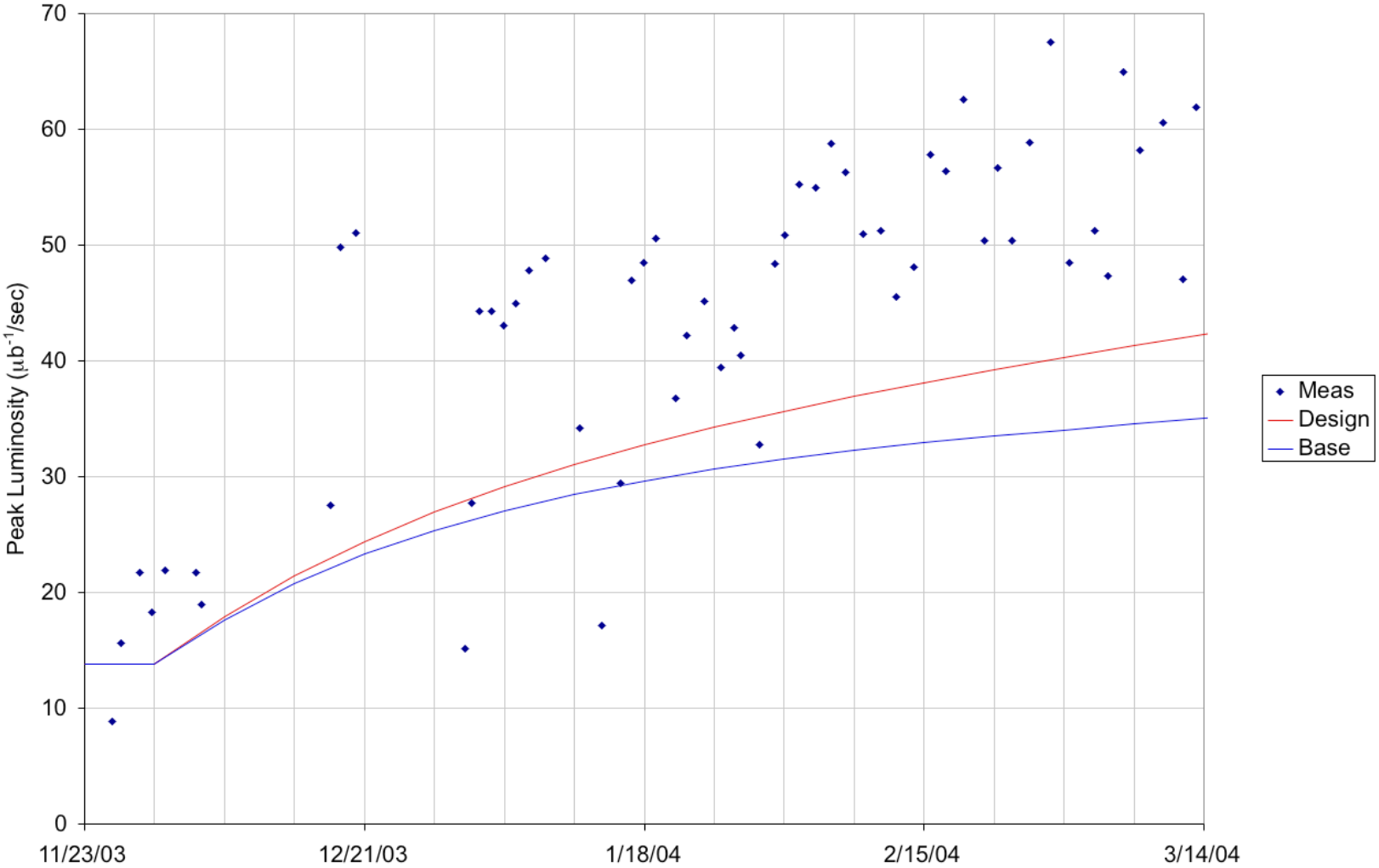
Data Summary Table

Store Parameters							
Parameter	Last Store	Last 10 stores Average	FY04 Average	End of FY03	FY04 (End) Design	FY04 (End) Base	
Initial Luminosity (Average)	51.5	55.9	47.9	36.1	61.9	43.3	$x10^{30}cm^{-2}sec^{-1}$
Integrated Luminosity per Store (Averaged)	1478	2571	2135	1089	2000	1300	nb^{-1}
Luminosity per week (Averaged)	-	10.4	8.5	6.4	11.3	7.4	pb^{-1}
Store Length	14.5	29.6	26.8	14.9	15.0	15.0	Hours
Store Hours per week	-	118	106	88	85	84	Hours
Shot Setup Time	2.6	2.5	2.6	2.3	2.2	2.2	Hours
TEVATRON Parameters							
Parameter	Last Store	Last 10 stores Average	FY04 Average	End of FY03	FY04 (End) Design	FY04 (End) Base	
Protons per bunch	231	241	229	237	260	260	$x10^{9}$
Antiprotons per bunch	25	30	28	22	31	25	$x10^{9}$
Proton Efficiency to Low Beta	82	81	78	58	-	-	%
Pbar Transfer efficiency to Low Beta	76	73	76	63	80	77	%
HourGlass Factor	0.72	0.70	0.70	0.70	0.65	0.65	
Initial Luminosity Lifetime	5.9	7.9	8.4	9.5	8.3	7.0	hours
Asymptotic Luminosity Lifetime	24.0	24.6	25.4	25.1	25.0	25.0	hours
Effective Emittance	17.0	20.0	20.2	21.6	21.0	23.0	π-mm-mrad
Antiproton Parameters							
Parameter	Last Store	Last 10 stores Average	FY04 Average	End of FY03	FY04 (End) Design	FY04 (End) Base	
Zero Stack Stack Rate	11.2	11.6	11.0	11.5	18.0	13.7	$x10^{10}$/hour
Normalized Zero Stack Stack Rate	2.2	2.3	2.2	2.3	3.6	2.7	$x10^{-2}$/hour
Average Stacking Rate	7.6	6.0	5.7	7.1	9.3	7.6	$x10^{10}$/hour
Stacking Time Line Factor	93	82	82	88	75	75	%
Stack Size at Zero Stack Rate	277	284	292	300	300	300	$x10^{10}$
Protons on Target	5.1	5.1	5.0	5.0	5.0	5.0	$x10^{12}$
Start Stack	129	169	157	144	155	130	$x10^{10}$
End Stack	12	17	25	16	15	15	$x10^{10}$
Unstacked Pbars	116	151	132	128	140	115	$x10^{10}$

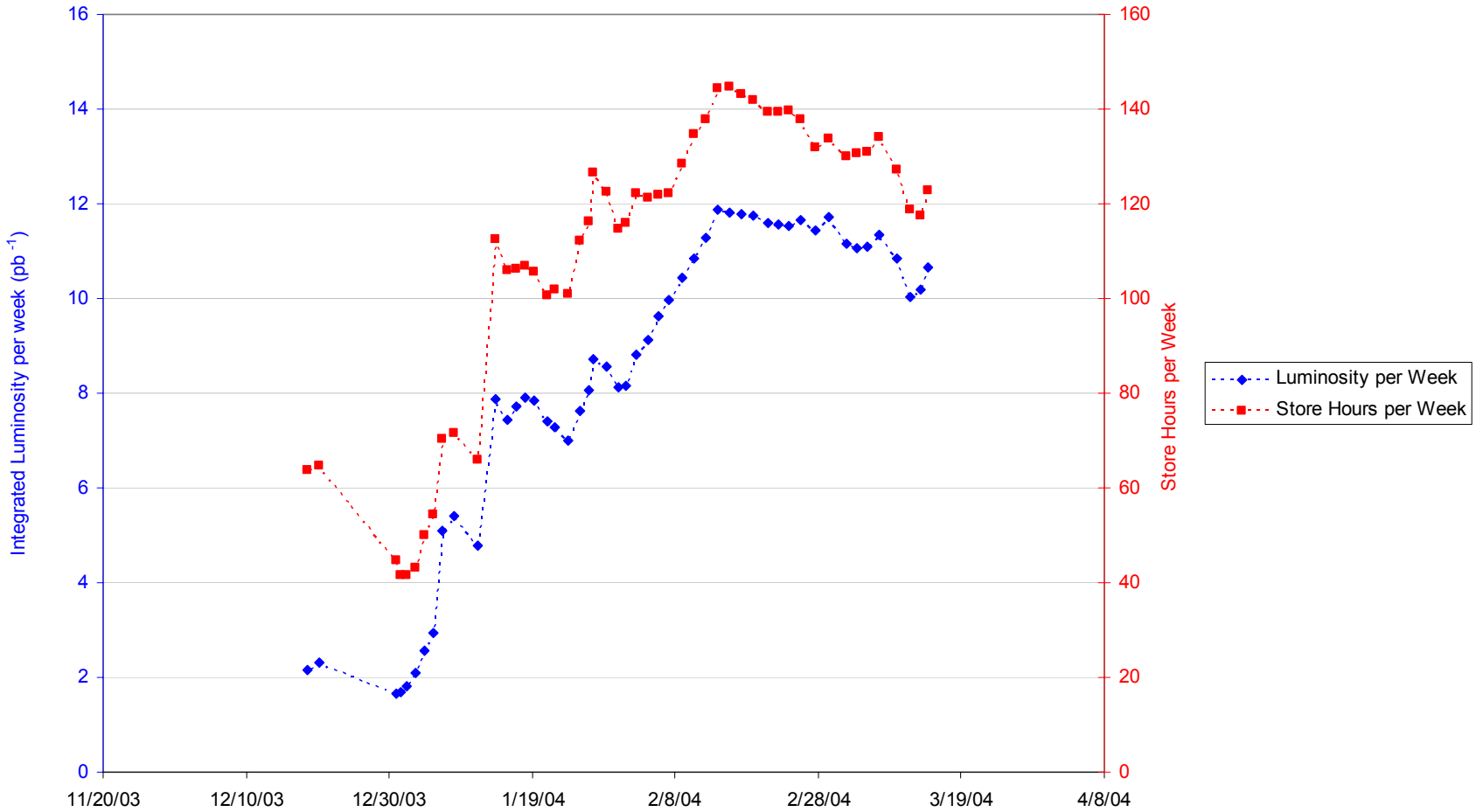
Luminosity Potential vs Stack size



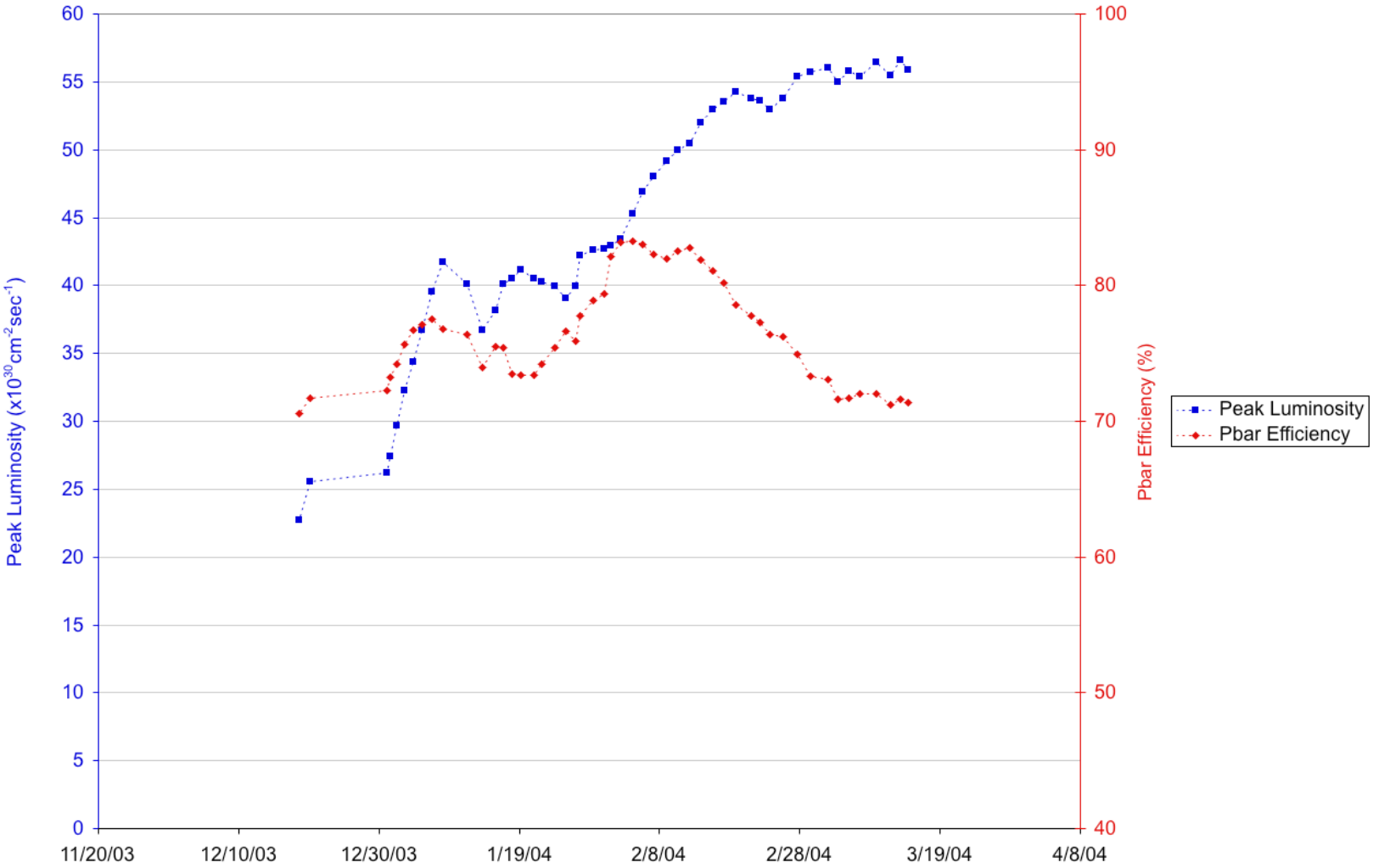
FY04 Peak Luminosity



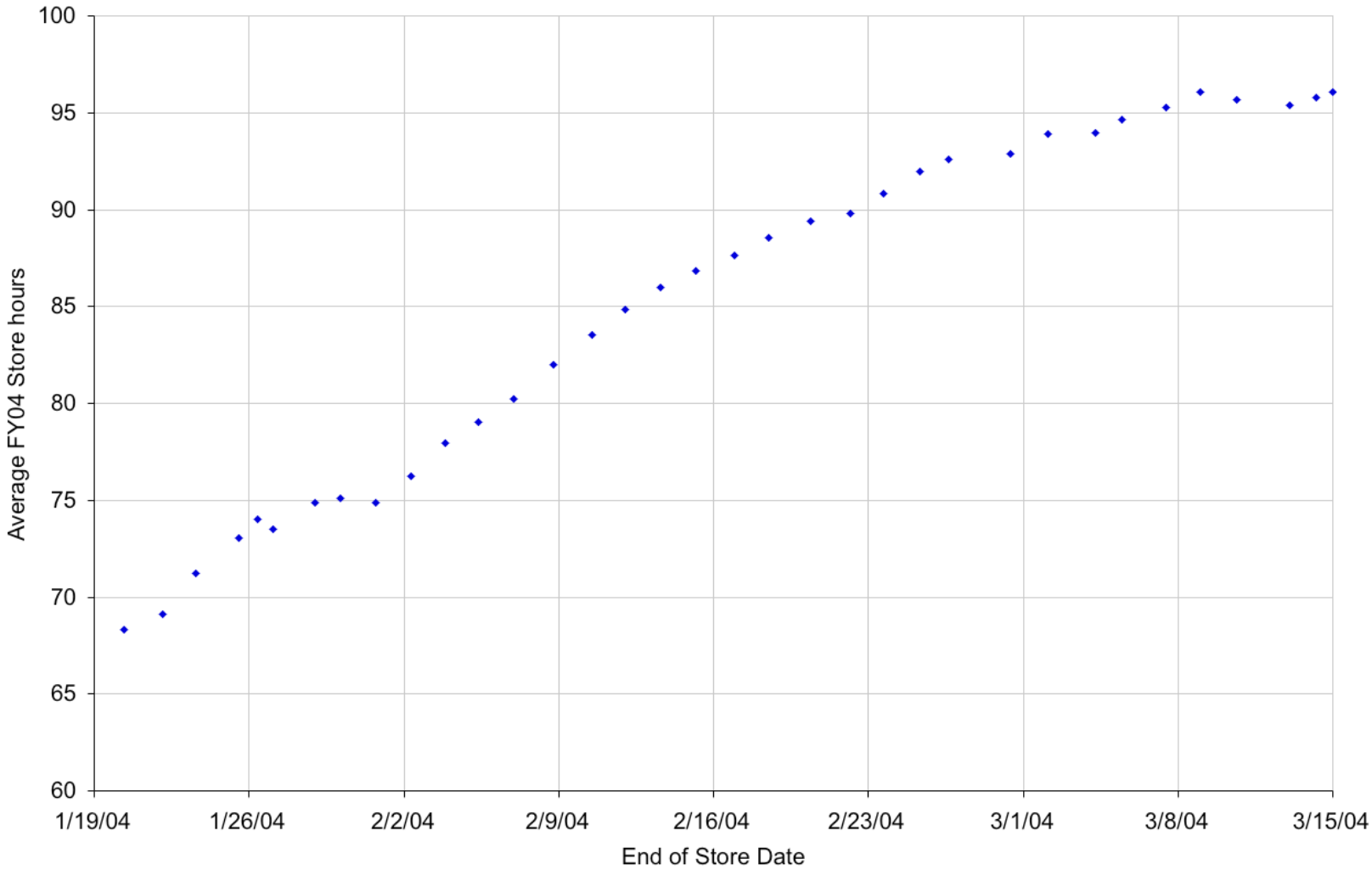
Luminosity Per Week (10 store running average)



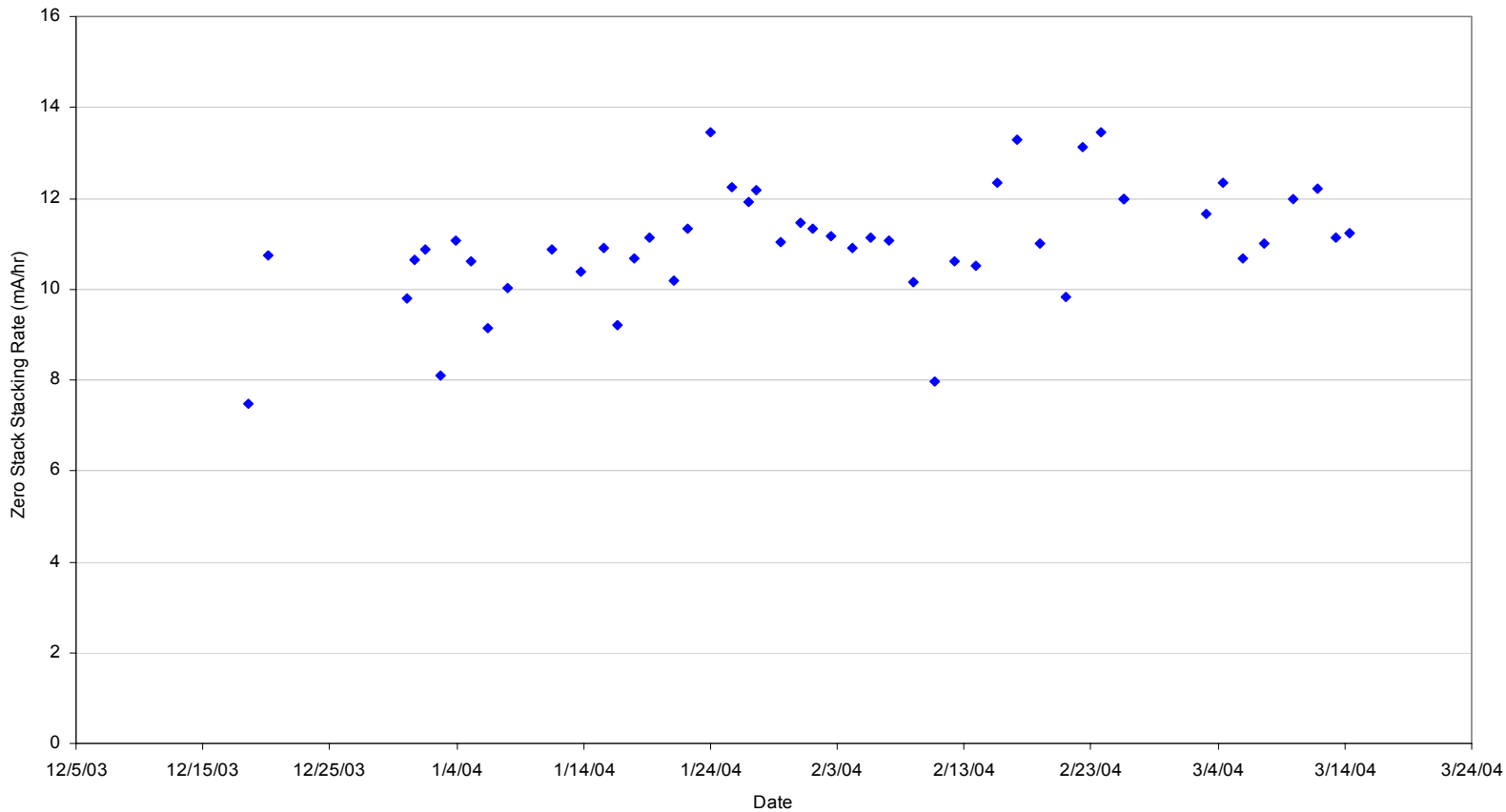
Peak Luminosity (10 store running average)



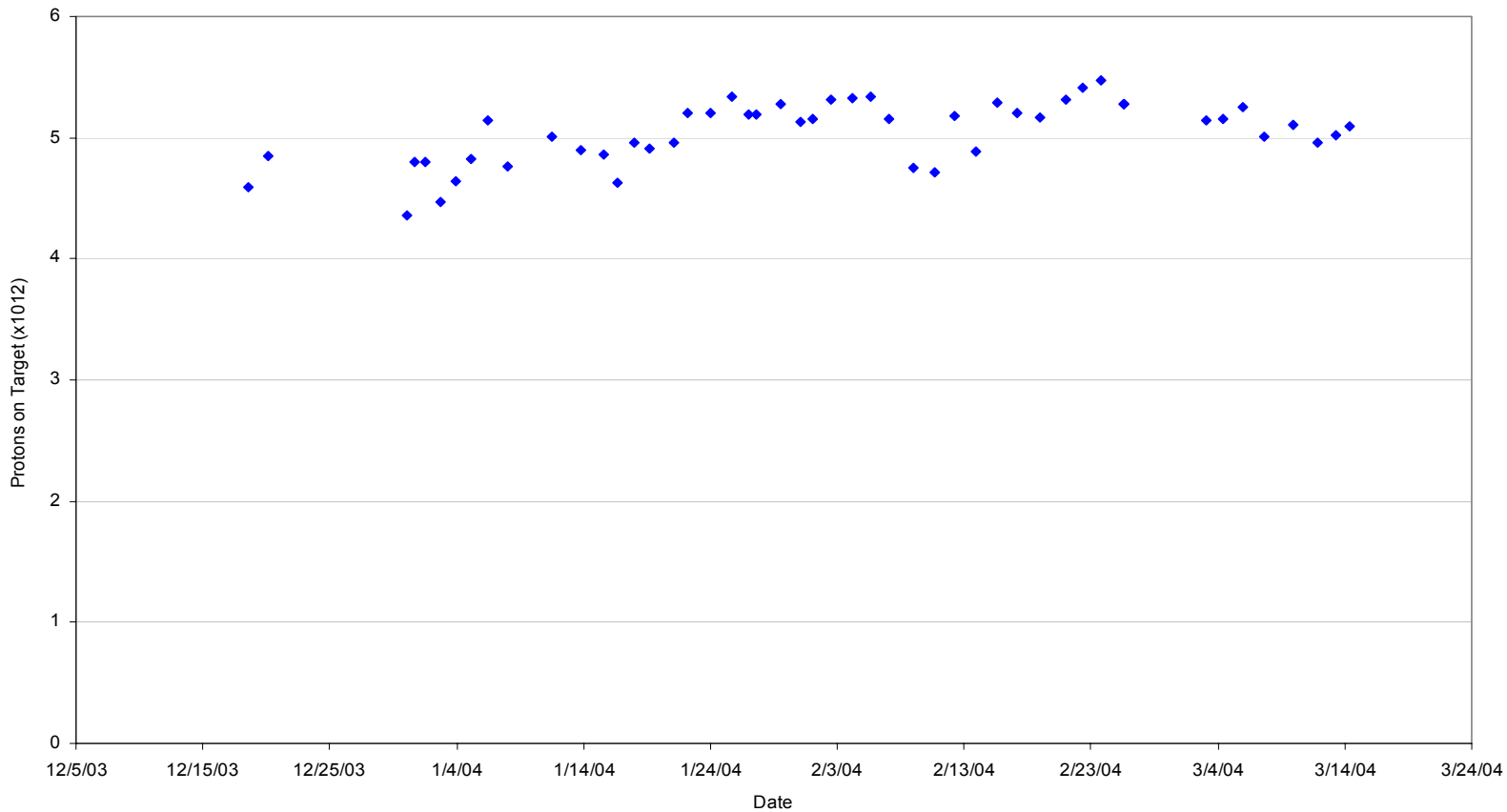
Average FY04 Store Hours



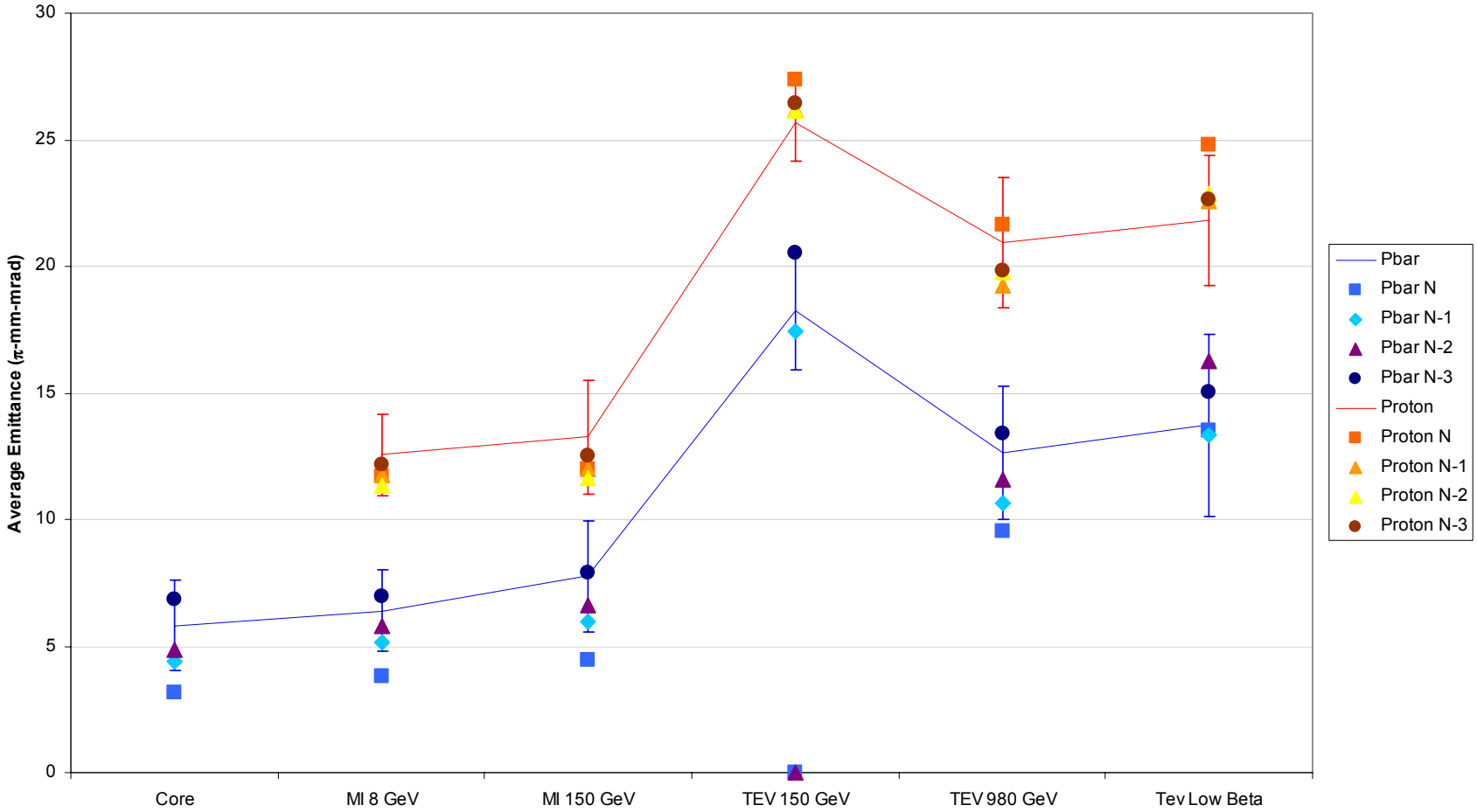
Zero Stack Stacking Rate



Protons on Target



Emittance Through the Acceleration Chain



Future Technical Challenges

- Stacking and Cooling
  - Increasing AP2 and Debuncher apertures
  - Improving the Debuncher cooling system
  - Stacktail Upgrade
  - Complete commissioning of the Recycler
  - Electron Cooling in the Recycler
- Beam Beam Interactions the Tevatron
  - TEL
  - Helices
- Install and Commission Electron Cooling in the Recycler
- Slip Stacking in Main Injector
- Reliability and Maintenance
  - 32-year-old Linac and Booster
  - 20-year-old Tevatron

Summary

- We have made good progress on Run II
  - Division Organization has been tailored to meet the challenges
  - Version 2.0 of Run II Plan is in place and we are following it
  - Run II operations is performing better than expectations.